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DEFLECTION
OF
P.V.C. PIPE
UNDER
BURIAL CONDITIONS

Pollution Control Branch

Ministry of the Environment

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By

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N O T I C E

The material presented in this paper has been prepared by extrapolating, using theory, from information believed to be correct.

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The use of these tables should not be considered as an alternative to engineering design specific to the structure under consideration.

DEFLECTION OF PVC PIPE UNDER BURIAL CONDITIONS

1.0 GENERAL

It is well recognized in the design of buried, non-pressurized (gravity flow) piping systems using flexible pipe such as that manufactured of Poly (Vinyl) Chloride (PVC), that the resistance of the pipe to deflection is provided by a combination of the inherent stiffness of the pipe and the lateral support provided by the soil around the pipe.

This concept was first stated formally by Spangler[1] in 1941 and the design formula as proposed by him and subsequently modified came to be an accepted method of flexible conduit design.

Difficulty in obtaining values for some of the required design parameters (notably the soil modulus of passive resistivity) has led to many attempts to develop alternative design methods but the modified Spangler formula remains theoretically sound and it is this method which is used in this paper.

2.0 DESIGN CONDITIONS

2.1 Deflection Formula:

As stated previously it is the modified Spangler formula, also known as the "Iowa formula" which is used in this paper. (The modified formula was developed in 1955 by Reynold K. Watkins[3]).

$$\Delta_x = \frac{D.K.Wc.r^3}{EI + 0.061E'r^3}$$

This has been further modified to incorporate measurable values of pipe stiffness in place of "EI" and as currently used is:

$$\Delta x = \frac{D.K.Wc}{0.149\ F/\Delta y + 0.061E'}$$

in which

D = lag factor

K = bedding factor

Wc = earth loading

$F/\Delta y$ = pipe stiffness

E' = soil modulus of passive resistance.

2.2 Design Assumptions:

2.2.1 D (lag factor)

The lag factor has been assigned on arbitrarily selected value of 1.5 in accordance with Spangler's work.

2.2.2 K (bedding factor)

The bedding factor depends on the amount of haunch support provided to the pipe by backfill and can vary from 0.008 for pipe on a flat surface to 0.110 for a pipe well supported to the spring line. For the tables herein, a value of K = 0.1 has been used for purposes of illustration.

2.2.3 Wc (earth load)

It was determined by Marston[2] that the earth

loading on flexible pipe is:

$$Wc = C_d.w.B_d.B_c$$

for a trench condition in which

C_d = soil dependant coefficient

w = soil density

B_d = trench width

B_c = conduit diameter

For the embankment condition this load becomes the "prism load":

$$Wc = H.w.B_c$$

This is the maximum earth loading to be expected and it is this value which has been used in computing the table values.

2.2.4 $F/\Delta y$ (pipe stiffness)

Pipe stiffness is a pipe characteristic which may be experimentally obtained (ASTM 2412) but which may also be obtained from theoretical consideration of pipe material and geometry. It may thus be shown that:

$$0.149\ F/\Delta y = 2/3\ [E/(DR-1)^3]$$

in which

E = material modulus of elasticity

DR = pipe dimension ratio
= outside diam/wall thickness

It is this value, using E = 2.758 x 10^6 kPa (400,000 psi) which has been used in preparing the tables.

2.2.5 E' (soil modulus of passive resistivity)

The soil modulus is essentially an unmeasurable quantity and has usually been determined experimentally by measuring pipe deflection under a known load and calculating the value of E' which would limit deflection to the measured value.

The values of E' used in this paper have been collected from several sources (3,4,5) (either as E' or by calculating from measured deflections). The values as used are essentially the same as those developed by Howard[5] and used by the U.S. Bureau of Reclamation.

The values presented in Table 1 are considered as representative for the soils if compacted to the specified (Proctor) density.

TABLE 1

Soil Classification	Proctor Density	E' kPa (psi)
Class I (angular gravel)	> 75%	21 x 10^3 (3000)
Class II (gravel)	90%	21 x 10^3 (3000)
	80%	7.0 x 10^3 (1000)
Class III (sand)	90%	14 x 10^3 (2000)
	85%	7.0 x 10^3 (1000)
	75%	2.7 x 10^3 (400)
	65%	2.0 x 10^3 (300)
Class IV (clay)	85%	5.5 x 10^3 (800)
	75%	2.7 x 10^3 (400)
	65%	2.0 x 10^3 (300)

3.0 COMPUTATIONS

For the modified Spangler formula:

$$\Delta x = \frac{D.K.Wc}{0.149\ F/\Delta y + 0.061E'}$$

in which

$$Wc = w.H.Bc$$

the pipe deflection, as a percent of the pipe diameter:

$$\left(\frac{\Delta x}{Bc}\right)\% = \frac{100.D.K.w.H}{0.149\ F/\Delta y + 0.061\ E'}$$

For $D = 1.5$

and conditions in which

$K = 0.1$

$w = 1925\ kg/m^3$ $(120\ lb/ft^3)$

$(9.8 \times 10^{-3} \times kg/m^3 \times m = kPa)$

the % deflection, δ, becomes

$$\delta = \frac{100 \times 1.5 \times 0.1 \times 9.8 \times 10^{-3} \times 1925 \times H}{0.149\ F/\Delta y + 0.061\ E'}$$

$$= \frac{283\ H}{0.149\ F/\Delta y + 0.061\ E'}$$

$$= \frac{283\ H}{2/3\ [E/(DR-1)^3] + 0.061\ E'}$$

(For use in SI units; H is in metres, E and E' in kPa)

Deflections of greater than 5% are not allowed under MOE policy and guidelines[6] and, therefore, are not included ("*** - not recommended") in the tables.

4.0 TABLE LIMITATIONS

The tabulated values should be considered valid only if the assumed values do, in fact, obtain under field conditions. Thus, the bedding factor, K, implies pipe haunch support by well tamped material to a bedding angle of approximately 60°. Similarly, a soil of density 1925 kg/m^3 (120 lb/ft^3) must be used and an embankment condition prevail. In a trench condition the earth loading as tabulated will be valid only if $C_d = H/B_d$. Also the values of E' are considered to be representative only if sufficient care is taken in the pipe installation to ensure that the assumed conditions prevail.

Again, it is emphasized that the tables presented are only representative guidelines and any value obtained for a specific case must be supported by appropriate engineering design.

MAXIMUM LONG TERM DEFLECTION OF PVC(DR=13)PIPE,PERCENT

ASTM EMBEDMENT MATERIAL CLASSIFICATION		DENSITY (PROCTOR) AASHO T-99	HEIGHT OF FILL (metres) 1	2	3	4	5	6	7	8	9	10
GRAVEL	CLASS I		0.1	0.2	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.2
GRAVEL	CLASS II	90%	0.1	0.2	0.4	0.5	0.6	0.7	0.8	1.0	1.1	1.2
		80%	0.2	0.4	0.6	0.8	0.9	1.1	1.3	1.5	1.7	1.9
		90%	0.1	0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.3	1.5
		85%	0.2	0.4	0.6	0.8	0.9	1.1	1.3	1.5	1.7	1.9
SAND	CLASS III	75%	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.8	2.1	2.3
		65%	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	2.1	2.4
		85%	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
CLAY	CLASS IV	75%	0.2	0.5	0.7	0.9	1.2	1.4	1.6	1.8	2.1	2.3
		65%	0.2	0.5	0.7	1.0	1.2	1.4	1.7	1.9	2.1	2.4
PEAT	CLASS V		THIS SOIL CLASS NOT RECOMMENDED									

MAXIMUM LONG TERM DEFLECTION OF PVC(DR=17)PIPE,PERCENT

ASTM EMBEDMENT MATERIAL CLASSIFICATION		DENSITY (PROCTOR) AASHO T-99	HEIGHT OF FILL (metres) 1	2	3	4	5	6	7	8	9	10
GRAVEL	CLASS I		0.2	0.3	0.5	0.7	0.8	1.0	1.1	1.3	1.5	1.6
GRAVEL	CLASS II	90%	0.2	0.3	0.5	0.7	0.8	1.0	1.1	1.3	1.5	1.6
		80%	0.3	0.6	1.0	1.3	1.6	1.9	2.3	2.6	2.9	3.2
		90%	0.2	0.4	0.7	0.9	1.1	1.3	1.5	1.7	2.0	2.2
		85%	0.3	0.6	1.0	1.3	1.6	1.9	2.3	2.6	2.9	3.2
SAND	CLASS III	75%	0.5	0.9	1.4	1.8	2.3	2.8	3.2	3.7	4.2	4.6
		65%	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
		85%	0.4	0.7	1.1	1.4	1.8	2.2	2.5	2.9	3.2	3.6
CLAY	CLASS IV	75%	0.5	0.9	1.4	1.8	2.3	2.8	3.2	3.7	4.2	4.6
		65%	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
PEAT	CLASS V		THIS SOIL CLASS NOT RECOMMENDED									

MAXIMUM LONG TERM DEFLECTION OF PVC(DR=21) PIPE, PERCENT

ASTM EMBEDMENT MATERIAL CLASSIFICATION		DENSITY (PROCTOR) AASHO T-99	HEIGHT OF FILL (metres) 1	2	3	4	5	6	7	8	9	10
GRAVEL	CLASS I		0.2	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.7	1.9
GRAVEL	CLASS II	90%	0.2	0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.7	1.9
		80%	0.4	0.9	1.3	1.7	2.2	2.6	3.0	3.4	3.9	4.3
		90%	0.3	0.5	0.8	1.0	1.3	1.6	1.8	2.1	2.3	2.6
		85%	0.4	0.9	1.3	1.7	2.2	2.6	3.0	3.4	3.9	4.3
SAND	CLASS III	75%	0.7	1.4	2.2	2.9	3.6	4.3	5.0	***	***	***
		65%	0.8	1.6	2.4	3.2	4.0	4.8	***	***	***	***
		85%	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0
CLAY	CLASS IV	75%	0.7	1.4	2.2	2.9	3.6	4.3	5.0	***	***	***
		65%	0.8	1.6	2.4	3.2	4.0	4.8	***	***	***	***
PEAT	CLASS V		THIS SOIL CLASS NOT RECOMMENDED									

***-NOT RECOMMENDED

MAXIMUM LONG TERM DEFLECTION OF PVC(DR=26) PIPE, PERCENT

ASTM EMBEDMENT MATERIAL CLASSIFICATION		DENSITY (PROCTOR) AASHO T-99	HEIGHT OF FILL (metres) 1	2	3	4	5	6	7	8	9	10
GRAVEL	CLASS I		0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
GRAVEL	CLASS II	90%	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0
		80%	0.5	1.0	1.6	2.1	2.6	3.1	3.6	4.2	4.7	5.2
		90%	0.3	0.6	0.9	1.2	1.5	1.7	2.0	2.3	2.6	2.9
		85%	0.5	1.0	1.6	2.1	2.6	3.1	3.6	4.2	4.7	5.2
SAND	CLASS III	75%	1.0	2.0	3.0	4.0	5.0	***	***	***	***	***
		65%	1.2	2.4	3.5	4.7	***	***	***	***	***	***
		85%	0.6	1.2	1.9	2.5	3.1	3.7	4.4	5.0	***	***
CLAY	CLASS IV	75%	1.0	2.0	3.0	4.0	5.0	***	***	***	***	***
		65%	1.2	2.4	3.5	4.7	***	***	***	***	***	***
PEAT	CLASS V	THIS SOIL CLASS NOT RECOMMENDED										

***-NOT RECOMMENDED

MAXIMUM LONG TERM DEFLECTION OF PVC(DR=28)PIPE, PERCENT

ASTM EMBEDMENT MATERIAL CLASSIFICATION		DENSITY (PROCTOR) AASHO T-99	HEIGHT OF FILL (metres) 1	2	3	4	5	6	7	8	9	10
GRAVEL	CLASS I		0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.9	2.1
GRAVEL	CLASS II	90%	0.2	0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.9	2.1
		80%	0.5	1.1	1.6	2.2	2.7	3.3	3.8	4.4	4.9	***
		90%	0.3	0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0
		85%	0.5	1.1	1.6	2.2	2.7	3.3	3.8	4.4	4.9	***
SAND	CLASS III	75%	1.1	2.2	3.3	4.4	***	***	***	***	***	***
		65%	1.3	2.6	3.9	***	***	***	***	***	***	***
		85%	0.7	1.3	2.0	2.6	3.3	4.0	4.6	***	***	***
CLAY	CLASS IV	75%	1.1	2.2	3.3	4.4	***	***	***	***	***	***
		65%	1.3	2.6	3.9	***	***	***	***	***	***	***
PEAT	CLASS V		THIS SOIL CLASS NOT RECOMMENDED									

***-NOT RECOMMENDED

MAXIMUM LONG TERM DEFLECTION OF PVC(DR=32)PIPE, PERCENT

ASTM EMBEDMENT MATERIAL CLASSIFICATION		DENSITY (PROCTOR) AASHO T-99	HEIGHT OF FIII (metres) 1	2	3	4	5	6	7	8	9	10
GRAVEL	CLASS I		0.2	0.4	0.6	0.8	1.1	1.3	1.5	1.7	1.9	2.1
GRAVEL	CLASS II	90%	0.2	0.4	0.6	0.8	1.1	1.3	1.5	1.7	1.9	2.1
		80%	0.6	1.2	1.7	2.3	2.9	3.5	4.1	4.6	***	***
		90%	0.3	0.6	0.9	1.2	1.5	1.9	2.2	2.5	2.8	3.1
		85%	0.6	1.2	1.7	2.3	2.9	3.5	4.1	4.6	***	***
SAND	CLASS III	75%	1.2	2.5	3.7	5.0	***	***	***	***	***	***
		65%	1.5	3.1	4.6	***	***	***	***	***	***	***
		85%	0.7	1.4	2.1	2.8	3.6	4.3	5.0	***	***	***
CLAY	CLASS IV	75%	1.2	2.5	3.7	5.0	***	***	***	***	***	***
		65%	1.5	3.1	4.6	***	***	***	***	***	***	***
PEAT	CLASS V	THIS SOIL CLASS NOT RECOMMENDED										

***-NOT RECOMMENDED

MAXIMUM LONG TERM DEFLECTION OF PVC(DR=35)PIPE, PERCENT

ASTM EMBEDMENT MATERIAL CLASSIFICATION		DENSITY (PROCTOR) AASHO T-99	HEIGHT OF FILL (metres) 1	2	3	4	5	6	7	8	9	10
GRAVEL	CLASS I		0.2	0.4	0.6	0.9	1.1	1.3	1.5	1.7	1.9	2.1
GRAVEL	CLASS II	90%	0.2	0.4	0.6	0.9	1.1	1.3	1.5	1.7	1.9	2.1
		80%	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	***	***
		90%	0.3	0.6	0.9	1.3	1.6	1.9	2.2	2.5	2.8	3.1
		85%	0.6	1.2	1.8	2.4	3.0	3.6	4.2	4.8	***	***
SAND	CLASS III	75%	1.3	2.7	4.0	***	***	***	***	***	***	***
		65%	1.7	3.4	5.0	***	***	***	***	***	***	***
		85%	0.7	1.5	2.2	3.0	3.7	4.4	5.2	***	***	***
CLAY	CLASS IV	75%	1.3	2.7	4.0	***	***	***	***	***	***	***
		65%	1.7	3.4	5.0	***	***	***	***	***	***	***
PEAT	CLASS V		THIS SOIL CLASS NOT RECOMMENDED									

***-NOT RECOMMENDED

MAXIMUM LONG TERM DEFLECTION OF PVC(DR=41) PIPE, PERCENT

ASTM EMBEDMENT MATERIAL CLASSIFICATION		DENSITY (PROCTOR) AASHO T-99	HEIGHT OF FILL (metres) 1	2	3	4	5	6	7	8	9	10
GRAVEL	CLASS I		0.2	0.4	0.6	0.9	1.1	1.3	1.5	1.7	1.9	2.2
GRAVEL	CLASS II	90%	0.2	0.4	0.6	0.9	1.1	1.3	1.5	1.7	1.9	2.2
		80%	0.6	1.2	1.9	2.5	3.1	3.7	4.3	5.0	***	***
		90%	0.3	0.6	1.0	1.3	1.6	1.9	2.2	2.6	2.9	3.2
		85%	0.6	1.2	1.9	2.5	3.1	3.7	4.3	5.0	***	***
SAND	CLASS III	75%	1.5	2.9	4.4	***	***	***	***	***	***	***
		65%	1.9	3.8	***	***	***	***	***	***	***	***
		85%	0.8	1.6	2.3	3.1	3.9	4.7	***	***	***	***
CLAY	CLASS IV	75%	1.5	2.9	4.4	***	***	***	***	***	***	***
		65%	1.9	3.8	***	***	***	***	***	***	***	***
PEAT	CLASS V	THIS SOIL CLASS NOT RECOMMENDED										

***-NOT RECOMMENDED

MAXIMUM LONG TERM DEFLECTION OF PVC(DR=42)PIPE,PERCENT

ASTM EMBEDMENT MATERIAL CLASSIFICATION		DENSITY (PROCTOR) AASHO T-99	HEIGHT OF FILL (metres) 1	2	3	4	5	6	7	8	9	10
GRAVEL	CLASS I		0.2	0.4	0.6	0.9	1.1	1.3	1.5	1.7	1.9	2.2
GRAVEL	CLASS II	90%	0.2	0.4	0.6	0.9	1.1	1.3	1.5	1.7	1.9	2.2
		80%	0.6	1.2	1.9	2.5	3.1	3.7	4.4	5.0	***	***
		90%	0.3	0.6	1.0	1.3	1.6	1.9	2.2	2.6	2.9	3.2
		85%	0.6	1.2	1.9	2.5	3.1	3.7	4.4	5.0	***	***
SAND	CLASS III	75%	1.5	3.0	4.4	***	***	***	***	***	***	***
		65%	1.9	3.8	***	***	***	***	***	***	***	***
		85%	0.8	1.6	2.3	3.1	3.9	4.7	***	***	***	***
CLAY	CLASS IV	75%	1.5	3.0	4.4	***	***	***	***	***	***	***
		65%	1.9	3.8	***	***	***	***	***	***	***	***
PEAT	CLASS V	THIS SOIL CLASS NOT RECOMMENDED										

***-NOT RECOMMENDED

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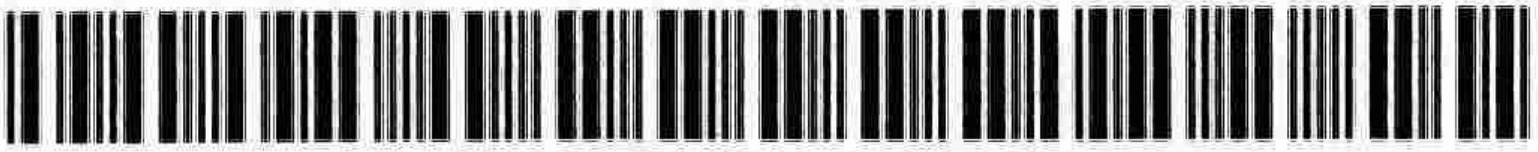
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